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Constraints on the Magnitude of Vertical and Lateral Mass Transport on the Moon
Final Report for NASA Award NAGW-4896

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Introduction and Overview

This final report for the grant NAGW-4896 covers the period 1/1/97-12/31/97. The main results have been published (Mustard and Head, 1996, attached) or are currently being reviewed in the refereed literature, which we expected to be completed by the fall of this year (Mustard et al., 1998; Li and Mustard, 1998, attached). This report serves to provide a modest amount of background material with the details to be found in the attached manuscipts which are in review or will be submitted for publication in the near future.

The role of vertical and lateral mass transport of crustal materials on the observed patterns of lunar surface composition, and the effects on our understanding of the geologic evolution of the planet, have been the subject of much debate in the lunar science community. The primary consensus that emerged from analyses of these processes in the 1970's and 1980's was that vertical and lateral mixing through impact gardening was a relatively inefficient process, and not likely to have contributed significantly to compositional units and variations on the Moon. The supporting evidence for this view is that unit boundaries (e.g. mare-highland contacts, contacts between mare color units) are still apparently quite distinct and sharp despite several aeons of impact activity, and cores from the Apollo landing sites did not show any evidence of widespread homogenization of the surface composition, nor distinct compositional gradients across geologic boundaries (e.g. McKay et al, 1991). In addition, modeling of vertical and lateral transport generally showed that the effects on composition should be confined to horizontal scales of about a kilometer and vertical scales of a meter (Arvidson et al, 1975; Quaide and Oberbeck, 1975; Langevin and Arnold, 1977).

The problem with this consensus is that there is ample contradictory evidence. The fundamental discovery of Wood et al. (1970) was made possible by significant horizontal transport of highland material to the center of Mare Tranquillitatis. The continuous and discontinuous ejecta from the crater Copernicus has clearly influenced the surface composition of a large area of the lunar maria, while rays and ejecta from many highland craters are easily recognized in and around the nearside maria. Despite this contrary evidence, there have been few detailed studies to quantify the amount and rate of material redistribution through impact processes (a notable exception is reported in the paper by Pieters et al, 1985), largely because data adequate to critically analyze this process were lacking. However, the multispectral images acquired by the Galileo and Clementine missions now permit the investigation of this process. In fact, recent studies using such data have shown that compositional gradients across mare-

highland contacts are the norm, though the specific characteristics (i.e. width, gradient, position relative to geologic contact) vary substantially (Fischer et al., 1995; Staid et al, 1994; Mustard et al, 1994; Mustard and Head, 1996). The availability of these new data thus provide an excellent opportunity to re-evaluate the importance of vertical and horizontal transport on the Moon and assess the currently available models.

The completed research contained two primary thrusts. The first was to characterize and quantify the amount of vertical and horizontal mixing across high-contrast geologic boundaries, principally mare-highland boundaries. This provided fundamental new data that was used to determine the importance of these processes in redistributing materials across boundaries. The second principal thrust was to related the observed abundance distributions to the fundamental geologic processes responsible for creating them. A third component of the research was the recognition that nonlinear mixing was a required analytical technique. The use of linear spectral mixture analysis was demonsrated to be inaccurate by as much as 15% absolute and 30% relative (Mustard et al., 1998).

Publications Resulting from this Award

PEER REVIEWED PAPERS (all attached)

Li, L. and J. F. Mustard, Compositional gradients across mare-highland contacts: The importance and geological implications of lateral mixing (*in preparation*), 1998.

Mustard, J. F., L. Li, and G. He, Nonlinear spectral mixture modeling of lunar multispectral data: Implications for lateral transport, (*submitted*) Journal of Geophysical Research-Planets, 1998.

Mustard, J.F. and J. W. Head Mare-highland mixing relationships along the southwestern shores of Oceanus Procellarum, J. Geophys. Res. 101, 18,913-18,925, 1996.

ABSTRACTS:

Li, L. and J. F. Mustard, Modeling of lateral transport on the Moon: Implications for impact cratering, Lunar and Planetary Science XXIX, #1926, 1998.

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Mustard, J. F., L. Li, and G. He, The importance of nonlinear mixture modeling for the analysis of lunar multispectral data, Lunar and Planetary Science XXVIII, 995-996, 1997.

He, G., and J. F. Mustard, The effects of nonlinear spectral mixture analysis on end-member optimization in analysis of hyperspectral image data, Lunar and Planetary Science XXVIII, 531-532, 1997.

L. Li, Mustard, J. F., and G. He, Mixing across simple mare-highland contacts: New insights from Clementine UV-VIS data of the Grimaldi basin, Lunar and Planetary Science XXVII, 751-752, 1996.

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Quaide, W. L., and V. R. Oberbeck, Development of the mare regoloth: Some model considerations, The Moon, 13, 27-55, 1975.

Staid, M. C. M. Pieters, J. W. Head, A multispectral view of stratigraphy in Mare Tranquillitatis, (abstr) Lunar and Planetary Science XXVI, 1345-1346, 1995.

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